Intercomparison of Simulated Arctic Snow on Sea Ice and Estimation of Snow-Related Feedbacks on Sea Ice

Cecilia M. Bitz
Atmospheric Sciences MS351640
University of Washington
Seattle, WA 98196-1640
phone: (206) 543-1339 fax: (206) 543-0308 email: bitz@uw.edu

Award Number: N00014-11-1-0550
http://www.atmos.uw.washington.edu/~bitz

LONG-TERM GOALS

The overarching goal of this project is to understand the impacts of climate change on Arctic sea ice related to the snow cover and to evaluate climate model projections of snow on Arctic sea ice.

OBJECTIVES

1) Evaluate the climatology of snow on Arctic sea ice among integrations submitted to the Fifth Coupled Model Intercomparison Project (CMIP5) that are evaluated for the Intergovernmental Panel on Climate Change Fifth Assessment. Compare models with observations from a snow atlas derived from Russian drifting stations and the IceBridge project measurements.
2) Evaluate trends in the 20th century integrations and evaluate the strength of the snow-related sea ice loss mechanisms in the past from models.
3) Evaluate the snow depth in future scenarios in terms of the pattern, local-scale snow distribution, and trends.
4) Contribute writing and figures about sea ice projections to the the Fifth Coupled Model Intercomparison Project (CMIP5)

APPROACH

Our team acquired and analyzed snow depth, sea ice area and thickness, and snowfall and rainfall rates in the Arctic for every fully-coupled, global climate model that was available in the CMIP5 archive. Undergraduate student Xiyue Sally Zhang downloaded the majority of the data and analyzed them. Graduate student Paul Hezel supervised Ms. Zhang and took over the analysis when Ms. Zhang left to go to graduate school. Mr. Hezel acquired observational data sets and compared models with observations. Mr. Hezel wrote the manuscript for our publication. Cecilia Bitz supervised the project and helped write the manuscript. Brendan Kelly, now at NSF, collaborated with us to inform us about the habits of ringed seals. Francois Massonnet, a graduate student at Louvain La Neuve in Belgium, collaborated with us by providing analysis of sea ice thickness. Both Massonnet and Kelly helped write

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the manuscript. Bitz worked with Massonnet to analyze the sea ice output in CMIP5 models for the IPCC AR5. Massonnet wrote a publication with help from Bitz.

WORK COMPLETED

The project is complete. We have downloaded and analyzed all of the model output from the CMIP5 archive. We compared models with observations. We wrote a manuscript, and it was published in September 2012. Paul Hezel included results from this project in his PhD dissertation. Bitz was a contributing author to the IPCC AR5 on the topics of sea ice projections, polar amplification, and sea ice reversibility.

RESULTS

We undertook the first analysis of snow depth on Arctic sea ice in the Coupled Model Intercomparison Project 5 (CMIP5). We find that snow depths in April on Arctic sea ice decrease over the 21st century scenarios. The CMIP5 scenarios of the 21st century are RCP2.6, RCP4.5, and RCP8.5, where RCP refers to Radiative Concentration Pathway and the number indicates the radiative forcing in Watts per square meter of the climate forcing. For reference, the forcing during the 20th century is about 1 W m^{-2}. The chief cause for lowering snow depths in the 21st century is loss of sea ice area in autumn and, to a lesser extent, winter. By the end of the 21st century in the RCP8.5 scenario, snowfall accumulation is delayed by about three months compared to the late 20th century in the multi-model mean. The loss of sea ice in autumn corresponds to a reduction in the area of ice that survives the melt season (hence a loss of multiyear sea ice).

Mean April snow depth north of 70N declines from about 28 cm to 16 cm. Precipitation increases as expected in a warmer climate, but much of this increase in the Arctic occurs as rainfall. The seasonality of snowfall rate grows, with increasing rates in winter and decreasing rates in summer and autumn, but the cumulative snowfall from September to April does not change. However, when accounting for the loss of sea ice as a platform to collect snow in autumn and early winter, the amount of snowfall that can accumulate is greatly reduced over the 21st century.

Ringed seals depend on spring snow cover on Arctic sea ice to create subnivean birth lairs. The area with snow depths above 20 cm — a threshold needed for ringed seals to build snow caves — declines by 70%. Thus the snow depth changes in the 21st century are expected to have a significant impact on Arctic ecology.

The multi-model mean April snow depth in the central Arctic compares well with observational estimates from two sources: a climatological mean from measurements made by the Soviet North Pole drifting stations from 1954–1991 by Warren et al. [1999] and transects in April 2009 from Operation IceBridge presented in Kwok et al [2011]. In CMIP5 models April snow depths in the central Arctic hold fairly steady throughout the 20th century and then decline sharply during the 21st. Observed snow depths are usually below average where much of the area is covered by firstyear sea ice. Even in regions that have a mixed population of firstyear and multiyear sea ice, April snow depths on multiyear sea ice are about double those on firstyear ice [Kurtz and Farrell, 2011]. Thus the observed areal distribution of snow on sea ice is consistent with our finding that snow depths are lowered as the Arctic transitions to primarily firstyear sea ice cover.

For a given forcing scenario, CMIP5 models may underestimate the decrease in wintertime accumulated snow depth for at least two reasons. First, rainfall rates in CMIP5 models increase during both the winter and spring, though the effect on net snow accumulation and morphology is not fully considered in the sea ice components of global climate models. Second, CMIP5 models do not simulate the effects of drifting snow, yet decreases in sea ice concentration in the autumn and early winter could also cause loss of drifting snow into leads. Changes to the sea ice surface topography (hummock height and distribution) are expected due to changes in the deformation rate as well as the proportion of firstyear and multiyear ice. The nature and seasonality of these changes and their effect on drifting snow is unknown.

IMPACT/APPLICATIONS

The considerable decline in 21st century snow depths in the CMIP5 models and the relevance for sea ice thickness and Arctic ecology motivate further investigation into the impact of these additional factors and further effort to improve snow physics in global climate models.

Modeling studies show that artificially enhancing the snow depth causes sea ice to become thinner via reduced growth rates at either pole [Maykut and Untersteiner, 1971; Huwald et al., 2005; Powell et al., 2005], provided the snow mass is insufficient to drive the sea ice-snow interface below sea level and cause snow-to-ice conversion (which we confirmed in our analysis). Since decreases in snow depth induce enhanced growth rates, we infer that reduced snow depths as the Arctic warms in the 21st century will lessen the thinning of sea ice.

Bitz contributed sections about sea ice projections, polar amplification, and sea ice revesiblity to the IPCC AR5, which will be available online on 30 September 2013. Her contribution was made possible through funding for this project. The IPCC is used by governments to make decisions about climate change policies. Sea ice loss and projections of sea ice loss is a major factor in these decisions.

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PUBLICATIONS

Hezel, P.J., X. Zhang, C.M. Bitz, B.P. Kelly, and F. Massonnet 2012: Projected decline in spring snow depth on Arctic sea ice caused by progressively later autumn open ocean freeze-up this century, Geophys. Res. Lett., 39, L17505, doi:10.1029/2012GL052794. [published, refereed]

Massonnet, F.; Fichefet, T.; Goosse, H.; Bitz, C. M.; Philippon-Berthier, G.; Holland, M. M.; Barriat, P. -Y. (2012). Constraining projections of summer Arctic sea ice. Cryosphere*, 6* (6), 1383-1394. [published, refereed]

Bitz, C.M. is a contributing author to the Intergovernmental Report on Climate Change Fifth Assessment Report, Chapter 12: Long-term climate change: Projections, Commitments, and Irreversiblity. Coordinating lead authors M. Collins and R. Knutti. [in press, refereed]

RELATED PROJECTS

None.

HONORS/AWARDS/PRIZES

Xiyuez Sally Zhang earned her Bachelor of Science degree from University of Washington and is now in graduate school at California Institute of Technology.

Paul Hezel completed his PhD at University of Washington and is now a Postdoctoral Fellow in Belgium at Louvain-la-Neuve.

Cecilia Bitz of the University of Washington is the recipient of the Rosenstiel Award in Oceanographic Sciences 2013 from the Rosenstiel School of Marine and Atmospheric Science at the University of Miami.

Cecilia Bitz of the University of Washington was awarded the American Geophysical Union Ascent Award in Atmospheric Science 2013.

Cecilia Bitz of the University of Washington was the Aggasiz Visiting Lecturer at Harvard University in 2013.

Cecilia Bitz of the University of Washington gave a congressional briefing on Arctic climate change in March 2013 and described results from this project.

Cecilia Bitz of the University of Washington gave a keynote lecture at the Bjerknes Center for the 10th Anniversary Celebration in September, 2012.

Cecilia Bitz of the University of Washington gave a keynote lecture at the European Center for Intermediate Range Forecasting Annual Symposium September, 2012.